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SPATIAL HETEROGENEITY IN PHENOLOGICAL DEVELOPMENT OF *PRUNUS PADUS* L. IN THE YEKATERINBURG CITY

ABSTRACT. The possible impact of the climate changes on vegetation is a key topic of various research studies in geography and ecology. In this study we tried to provide a «one-time survey» of the phenological development of *Prunus padus L*. in the Yekaterinburg city as a part of the large-scale project "A Single Phenological Day" and show the data on a map. The registration of a seasonal development of bird cherry was provided annually in the years of 2012-2018 on one and the same date in the city of Yekaterinburg, on 15 May. Yekaterinburg is the largest city located on the eastern foothills of the Middle Urals, Russia. The city has residential areas, parks, water reservoirs, as well as large industrial facilities that affect microclimatic conditions, resulting in an increase of the temperatures. Such microclimatic heterogeneity results in uneven development of bird cherry in spring. It was revealed the slowing of the bird cherry development in the areas situated close to large water reservoirs. At the same time bird cherry trees growing inside large industrial areas, on the contrary, developed much faster. The development rates of *Prunus padus L.* also differed though years: in years with dry and warm weather during the period of late April - early May the vegetation began earlier.

KEY WORDS: phenology, urban vegetation, *Prunus padus L.*, The Nationwide Phenology Day

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INTRODUCTION

The study of the spatial and temporal variability of seasonal nature phenomena is very important issue of modern geography and landscape ecology. In particular, the study of variability and inter-annual fluctuation in vegetation phenology is one of the simplest and low-cost approach to analyze changing weather and climate conditions. The timing of the onset of seasonal phenomena allows to indicate local and regional changes in climatic variables affecting plant development over growing season.

The concept of global phenology monitoring was formulated first in 1977 by Vladimir Batmanov (Yantser et al. 2010), the founder of the Ural phenological school. This idea was based on simultaneously registering the stage of seasonal development of a certain distinct species by numerous observers on a wide geographical area. The object of study (as *Prunus padus L.* in our researches) should be widespread, well-known and easily observed. Due to the insufficiency of the theoretical and methodological background this approach for a long time remained theoretical. In 2000, the several research teams of the Ural phenological school began to develop methods for global phenological observations (Kupriyanova 2010), however, this process was delayed, and only by 2012 the idea of V.A. Batmanov was turned into a global research project – The Nationwide Phenology Day (NPD).

Since 2018, the Russian scientists carry out the observations in almost all regions of the research object distribution in natural growth conditions (Yantser 2018). The teams involved in the observations are extremely diverse: from research scientists to junior schoolchildren.

The retrospective analysis of geographic and biological research suggests that with using phenological observations is possible to specify the degree of influence of the urban microclimate on the timing of the onset of seasonal phenomena. Within the framework of the project «NPD» we have attempted to visualize the influence of urban and suburban environment on vegetation.

The seasonal phenomena and effects of climate changes on plant and animal phenology are studied in different climatic regions from a variety of perspectives. The academics have a lot of publications devoted to the effect of climate change on the phenology of plants and animals. Among them, regional scale studies prevail, such as the reaction of some tree species to changes in the thermal conditions in the French Alps (Asse et al. 2018); phenological observations of the Betula genus in Europe (Siljamo et al. 2008), the studies of the generative cycle (flowering) in the Canadian subarctic ecosystems.

The seasonal development of plants is studied from both perspectives: plant physiology and ecology (Cleland et al. 2007; Clark et al. 2014), and geography. The studies was mainly focused on researches of species-specific responses of plants to climatic changes in the Northern Hemisphere (Minin 2002, 2006; Golubyatnikov 2009; Grebenyuk and Kuznetsova 2012; Soloviev 2015; König et al. 2018), also was studied the interannual variability of seasonal phenomena in relation to air temperature (Menzel and Sparks 2007), early spring index (Schwartz 1990), phenology of flowering plants (Tooke and Battey 2010), influence of some environmental factors on individual phenophases of woody plants (Penuelas 2001; Kulygin 2001; Körner and Basler 2010), as well as plant response and climate phenology (Richardson et al. 2013).

It was investigated the differences in the onset of seasonal processes both in natural conditions and in the urban areas (Kuklina and Danchenko 2009; Gorton et al. 2018); features of phenophases in large cities (Kulagin and Nikolaeva 2014; Ufimtseva and Terekhina 2017) and the effect of artificial lighting on plant development. Modeling and forecasting of seasonal processes are less studied issues, however, they hold a specific place as a promising direction. Scientists pay much attention to the methodological issues of the organization of phenological networks in various territories and their data processing (Visser and Both 2005; Kane and Beery 2009; Denny et al. 2014; Gerst et al. 2016).

MATERIAL AND METHODS

For the 40-year period from 1890 to 1930 the average date of *Prunus padus L*. blossoming shifted from was May 24 to May 19 (Batmanov 1952). Currently the average monthly spring temperatures are much higher than during the mentioned period, and thus, we decided to select May 15 for the uniform phenology observations. *Prunus padus L*. was selected as a uniform study species. The blooming of *Prunus padus L*. marks the beginning of the last period of spring and is often accompanied by a temperature drop and a stable rise in average temperatures (Minin and Voskova 2014). The number of observers exceeds several hundred people thought the county. To ensure a distinct registration we have developed a simple list of phenological states with a number code. Each phenophase has its own digital characteristic. For example, "code 1" is representing the winter dormancy phase, "code 2" - gemmation phase, "3" – the budding phase, etc.

To identify the peculiarities of the seasonal dynamics of the species in urban areas, phenological surveys were carried out in Yekaterinburg and its surroundings. The observer was asked to choose a *Prunus padus L*. tree or bush as a constant observation object for several years and to describe its phenological state each year on May 15, using the corresponding number code and to report to the Scientific and Educational Phenological Center.

Yekaterinburg is a big city situated in the eastern foothills of the Urals. The climate of the region is moderately continental. The mean annual temperature equals +3.0°C, mean temperatures of January and July are -12.6°C, and +19.0°C corresponsive. The annual temperature range reaches 33°C. Mean annual precipitation is about 540 mm. In general, the climate is characterized by long winters (up to 5 months) with stable snow cover in winter time, short transitional seasons, late springs and early autumn frosts, short frost-free periods (110–120 days), short summers (70–94 days); the timing of the transitional seasons is not stabile. Spring is characterized by warm and cold periods, that are associated with the meridional atmosphere circulation clearly manifested on the eastern macro slope of the Urals. The air temperature in the daytime can rise to + 24°C, and drop below 0 at night.

The microclimatic data was studied in the 1970s by the Sverdlovsk (former name of Yekaterinburg) weather control and environmental monitoring service made a series of field meteorological observations within the city boundaries and in its suburbs (Morokov and Shver 1981) within the city at seven plots. All observation points can be divided into several types depending on location: weather stations, parks, squares, lawns, city ponds and residential areas. Studies of the temperature dynamics in the "city-suburb" gradient show that the temperatures in the central regions of the city are higher than those in the outskirts by 0.2-0.6°C on average throughout the year; sometimes reaching up to 5°C. The vegetation rates depend on the moisture content in the soil after the spring snowmelt. In the second half of spring, due to the predominantly anticyclonic weather character, the rainfall level is low influencing the rates of *Prunus padus L*. seasonal development.

RESULTS AND DISCUSSION

Based on the previously mentioned researches we calculated the average score within a period of seven years for each object. We plotted these scores on the map of the city of Yekaterinburg in accordance with the location of the observation points (Fig. 1).

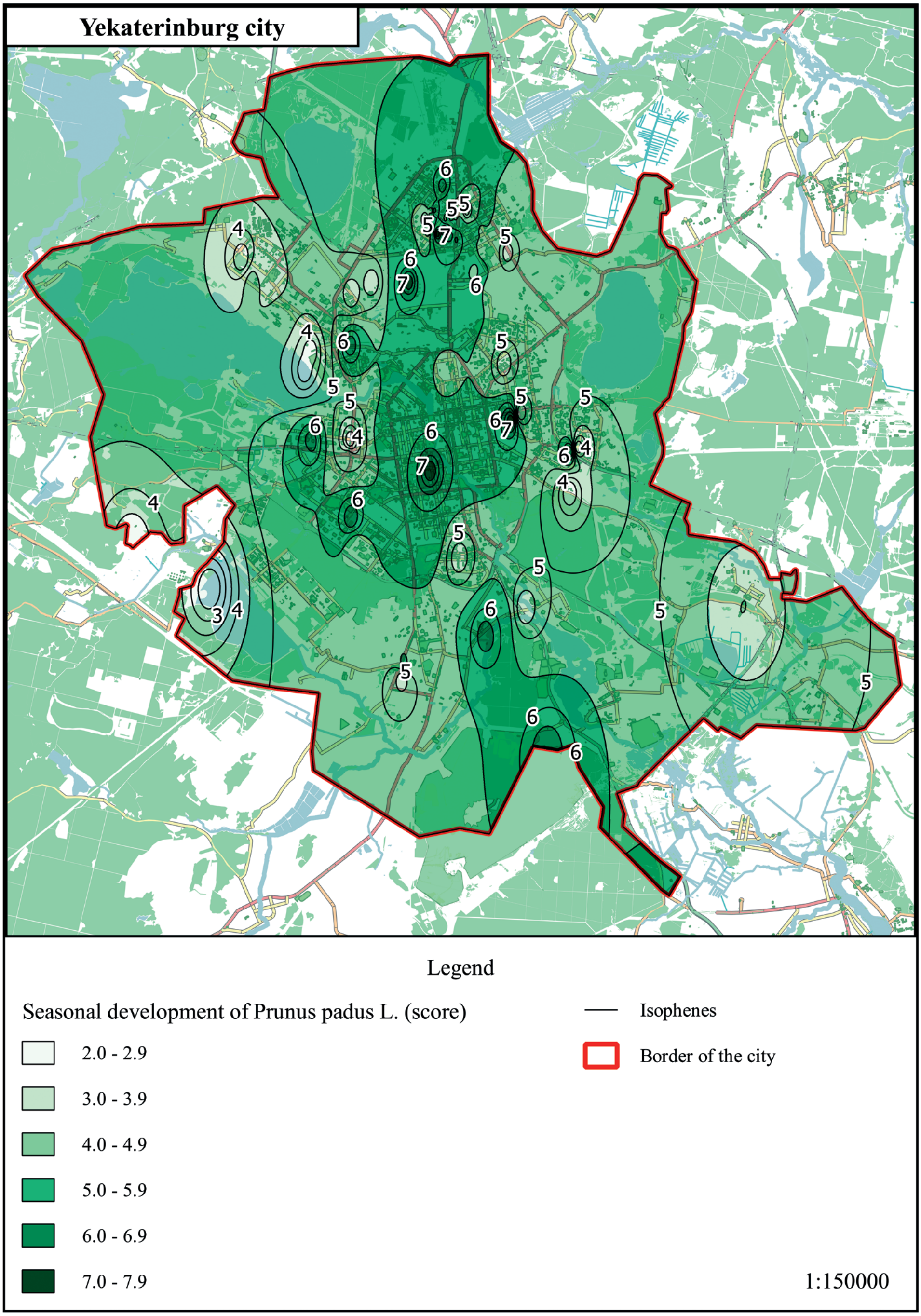

Fig. 1. The map of the average phenological state of *Prunus padus* L. as of May 15 in Yekaterinburg

We compared the average rate of phenological development in the city and its deviations from the multiyear average, as well as meteorological indicators that may influence spring development of the studied species (Table 1) thus receiving data on the temporal variability of vegetation period of *Prunus padus L.* in spring on the territory of Yekaterinburg.

The map clearly shows the lag in the outskirts of the city in relation to its center (Fig. 1). These results correspond with the results of the microclimatic observations (Morokov and Shver 1981). The most densely populated central and northern regions of Yekaterinburg are characterized by the earliest vegetation phases. The high points in terms of vegetation in the north of the city are driven by the area of heat above the large industrial area of Uralmash. According to meteorological observations, Uralmash region is warmer than the city center by 1.5°C, and the suburbs by 3-4°C. The lag was recorded near such large waterbodies as – Shartash and Shuvakish lakes and Verkh-Isetsky pond, as well as in the marshy southwest, east and southeast of the city. The lakes of the city produce a greenhouse effect at night and anti-greenhouse effect in daytime. Since they are cited in deep valleys, their effect extends only to 200-300 m of the coastal strip. The cold air stagnation adds to the effect.

The observations have shown that the temperature of lawns and areas with a natural coating is 2-2.5°C lower than the temperature around city squares. This is confirmed by the highest rates of phenological development of *Prunus padus L.* around them. The district of the Uktussky Mountains, located in the southeast of the city, is colder than the center by 3-4°C. This is confirmed by the fact that the vegetation scores of *Prunus padus L.* here are 1 point lower than in the city center.

The results of the studies of the vegetative period of *Prunus padus L.* are presented in Table 1. The long-term average phenological score on May 15 is 6.5. In the years

Table 1. Dynamics of phenoclimatic indicators for the period 2012-2018 in Yekaterinburg

Year	2012	2013	2014	2015	2016	2017	2018
Average of phenological development	7.8	6.5	8.2	7.0	7.8	5.8	2.3
Deviation from the multiyear average	-1.3	0.0	-1.7	-0.5	-1.3	+0.7	+4.2
First day with average daily air temperature above 0°C	19.03	16.03	09.03	10.03	25.03	21.02	03.04
Date of steady transition of average daily air temperature to positive values	02.04	03.04	12.04	31.03	25.03	06.04	03.04
∑ of air temperatures >0°C	431.6	299.9	323.0	318.2	379.4	310.8	213.8
∑ of air temperatures >+5°C	402.3	273.0	303.2	241.5	322.6	277.2	158.6
∑ of precipitation from 01.11 to 15.05 (mm)	138.1	236.4	230.5	142.0	210.3	188.2	148.6
∑ of precipitation from 01.05 to 15.05 (mm)	23.8	16.9	17.6	32.4	3.3	11.1	7.7
The average temperature of the first half of May (°C)	10.9	9.5	14.5	11.3	9.5	9.4	8.0

characterized by the greatest amount of accumulated heat and small amount of precipitation early vegetation is registered. In most cases the crucial factors are the arrival of heat in the first half of May and low rates of precipitation. Minimal deviations in the phenological development of *Prunus padus L*. were recorded in years with meteorological parameters close to the mean ones. The greatest delay in vegetation of *Prunus Padus L* relative to the average score at the NPD date was recorded in year 2018 -4.2 points. This was driven by the significant lag of all temperature characteristics and the latest transition of the average daily temperature to positive values within the last 7 years. Although 2014 was the most advanced in terms of phenological development, it was not characterized by the earliest transition of average daily temperature to positive values and had moderate amounts of accumulated heat. There was quite a large amount of precipitation in the first half of May. The significant increase in air temperature at the beginning of the second decade of May (to 16–24°C) had a decisive influence on the acceleration of the phenological development of the *Prunus padus L*.

CONCLUSION

The urban environment has a significant impact on the spatial and temporal structure of the seasonal development of *Prunus padus L*. The obtained results revealed the large differences in the timing of the *Prunus padus L*. growing season in the urban (artificial) and suburban (natural) environments. Such results resemble with the results of similar studies obtained particularly for two species of birch in the city of Tomsk (Kuklina 2009). Thus, we can conclude that in the cities vegetation begins earlier than in the suburbs of both birch, and bird cherry. The higher temperatures of the central areas od the city drive faster development of the *Prunus padus L*., especially in highly populated areas. Warm temperature periods during late April-early May along with the dry weather conditions trigger early *Prunus padus L*. seasonal development. We plan to continue the study in order to reveal shifts in *Prunus padus L*. spring seasonal development. The further study of suburban-urban differences in the vegetation period on will reveal the spatial characteristics of plant phenology. With the accumulation of data, the results of this study can help in a detailed understanding of the time shifts in plant phenology under the influence of climate change. Also, the calculation of the developmental anomalies of *Prunus padus L*. in days is more explicit and promising.

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